Experimenting Long Range Wide Area Network in an e-Health Environment: Discussion and Future Directions

Nagib Matni*, Jean Moraes*, Lucas Pacheco*, Denis Rosário*, Helder Oliveira*,
Eduardo Cerqueira*, and Augusto Neto†‡
* Federal University of Pará (UFPA), Belém – Brazil
† Federal University of Rio Grande do Norte (UFRN), Natal – Brazil
‡ Instituto de Telecomunicações (IT) – Portugal
Email: {nagib, denis, heldermay, cerqueira}@ufpa.br, {jean.anjos.moraes, lucas.pacheco}@itec.ufpa.br, augusto@dimap.ufrn.br

***Abstract*—Wearable devices/sensors and wireless networking play a pivotal role in enabling e-Health environments demanding biometry monitoring outside hospital facilities. In this regard, the Long-Range Wide-Area Network (LoRaWAN) technology is considered the most adopted wide area network since it promises ubiquitous connectivity in outdoor e-Health applications while keeping network structures and simple management, recently gained interest from the research and industrial community. However, the coexistence of high-dense wireless sensors brings several issues to LoRaWAN, such as high interference and channel congestion. In this paper, we introduce assessments on the LoRaWAN in an e-Health scenario by modeling wireless sensor traffic and implementing it on a network simulator. Simulation results suggest that while LoRaWAN can be extremely useful, by providing communication to thousands of simultaneous users, but its MAC layer structure and design limits significantly. We also introduce future research directions driven by the simulation results and LoRaWAN characteristics, for the goal to improve LoRaWAN performance in an e-Health scenario.**

***Index Terms*—LoRaWAN, e-Health, IoMT, and open issues.**

I. INTRODUCTION

The Internet of Medical Things (IoMT) refers to the heavy use of sensor technology to collect, analyze, and distribute health information via the web to make healthcare smarter [1]. The innovation brought by IoMT will affect almost all services necessary for economic development, as well as improve citizen's wellness and quality of life [2]. In light of this, e-Health institutions have been investing IoMT solutions to apply in preventive medicine programs as an attempt to reduce hospital check-ins and costs [3]. Remote patient monitoring is gaining acceptance from health professionals and specialists due to the advantages with regard to patients, care providers, and public health authorities. The benefits includes better outcomes and quality in treatment, real-time support and interventions, improved disease management, error reduction, prevention in emergencies and re-admissions, and reduced hospital stays and contamination. Home-assisted living, home care, and health park are only examples of IoT-empowered e-Health-footprinted verticals targeting remote patient monitoring [2].

The innovations in IoMT are redesigning e-Health in the form of new medical therapies, faster diagnosis, and decision-making [4], where the increasing popularity of wearable devices enhances the development of applications aimed to provide continuous remote patient monitoring [5]. In this context, wearable IoMT devices can sense, collect, and transmit biometry data continuously, leveraging for this onboard radio wireless facility to communicate with a gateway, which in turn delivers the collected data across the Internet to an e-Health system [4]. Pulse rate, Electrocardiogram (ECG), Electroencephalogram (EEG), blood glucose levels, accelerometer, and others are examples of non-invasive monitoring health conditions during diagnosis and treatment in e-Health scenario.

Monitored patients might have multiple body sensors, *i.e.*, wearable IoMT devices, to afford continuous biometry monitoring, where the collected data are transmitted to e-Health applications running on cloud servers [6]. Such cloud e-Health applications require immediate access to biometry information to carry out a high precision diagnosis. In this sense, e-Health applications have stringent requirements of packet delivery and traffic delay to ensure accurate information for medical staff [7]. Hence, the e-Health environment demands biometry monitoring outside hospital facilities, where wearable IoMT devices/sensors and wireless network plays an important role to provide an efficient solution [5].

Long-Range Wide-Area Network (LoRaWAN) technology, emerges as enabling IoMT technology, being considered the most adopted low power technology for its ubiquitous connectivity capacities in outdoor e-Health use cases. Moreover, LoRaWAN is attracting attention from both academy and industry to connect wearable IoMT devices that require long-range, low bandwidth, low power, and low-cost communication characteristics as expected in e-Health applications [7]. [8]. In LoRaWAN architecture, wearable IoMT devices send data to the application server via gateway over a single-hop wireless communication, covering an area with tens of kilometers and serving thousands of devices demanding less-complex access medium control at the expense of low throughput [8]. However, increased number of IoMT devices brings several problems, such as interference and channel congestion [1].

In this paper, we introduce a simulation testbed in which an e-Health environment, leveraging LoRaWAN connectivity

978-1-7281-3129-0/20/$31.00 ©2020 IEEE

service, participate. In order to model the e-Health use case, wireless sensor traffic is integrated into a LoRaWAN network on the NS-3. Simulation results suggest that LoRaWAN can be extremely useful in affording wireless communication to thousands of simultaneous users, to the cost of introducing limited scalability capabilities in the system. The reason is that the network overload exponentially increases with higher sensor density, leading to higher signal interference. Thus, the resulting packet loss caused by collisions jeopardizes the Quality of Service (QoS) of e-Health applications delivered by LoRaWAN. We also discuss some future research directions in order to improve LoRaWAN performance on IoMT scenario.

The rest of the paper is organized as follows. Section II outlines existing works and their main drawbacks. Section III introduces some concepts of LoRaWAN applied to IoMT. Section IV discusses the simulation description and results. Section V discusses key research challenges based on the simulation results and LoRaWAN characteristics. Finally, Section VI introduces the conclusions and future works.

II. RELATED WORK

Sanchez-Iborra *et al.* [9] introduced a comprehensive evaluation of LoRa under different real smart environment verticals, namely, urban, suburban, and rural. A discussion about the most proper LoRa physical-layer configuration for each aforementioned scenario is provided considering both dynamic and static conditions. However, a small number of devices participating in the evaluation. Furthermore, there is no stress enough to introduce a packet collision problem.

Pasolini *et al.* [10] presented two smart city simulation testbeds developed in Italy, which highlights different technologies and network topologies, even when addressing the same urban scenario. The first testbed concerns a smart infrastructure for public lighting vertical and relies on a heterogeneous network using the IEEE 802.15.4 short-range communication technology. The second testbed, in turn, addresses the smart-building vertical and is based on the LoRa low-rate, long-range communication technology. The findings of this work suggest that in an attempt to cover large urban areas and keep packet losses at satisfactory levels by maintaining the airtime sufficiently low, proper parameter settings are needed.

Buyukakkaslar *et al.* [11] investigated data transmission capabilities of the LoRaWAN technology in health care systems, assuming the benefits coming from the standard modulation technique in the delivery of critical data in the presence of noisy environments. The authors implemented the MAC layer in the Matlab tool so that simulating the protocol and carrying out a test efficiency concerning LoRa WAN standard data frame transmissions. The simulation outcomes provide evidence that the successful packet transmissions are directly affected by the node count.

Catherwood *et al.* [12] introduced an 868 MHz LoRaWAN-enabled personalized healthcare device capable of the remote monitoring of patients that suffer from a chronic condition and who has been sent home from the hospital. The tests suggest the suitability of the proposed device in the remote monitoring use case, thus proving that the IoMT is a promising solution to deal with chronic illness monitoring.

Park *et al.* [13] introduced a QoS study with regard to wireless-served healthcare use cases. The authors firstly investigate the essential QoS requirements that medical applications raise. Then, they show that the standard QoS metric of the Packet Error Rate (PER) is inefficient in assessing the QoS level of medical applications. As a standard application, they present a medical-grade QoS metric for wireless ECG transmission. Their simulation results show that there can be a significant difference between WDD and PER, which reinforces the importance of developing a medical-grade QoS metric by adequately taking into account the critical characteristics of medical traffic.

Overall, recent studies evaluated performance of LoRaWAN technology but limiting the number of devices. However, to the best of our knowledge, this is critical to understanding the behavior of a LoRaWAN when serving an e-Health vertical. Furthermore, it is important to introduce a discussion on a sort of future research directions envisioning to improve LoRaWAN performance in mission-critical use cases.

III. LORAWAN TECHNOLOGY TAILORED TO E-HEALTH WEARABLE IOMT SCENARIO

In future e-Health scenarios, patients might have multiple wearable IoMT devices affording continuous monitoring of biometry data, which must be transmitted to a cloud server for data analysis and storage. In this section, we introduce the application requirements for an e-Health environment, enabling to monitor the patient's condition in real-time remotely. The collected data must be transmitted over e LoRaWAN technology, which is also detailed in this section.

A. e-Health Environment

Offering efficient e-Health systems is one of the most important social and economic challenges nowadays. e-Health administrators, clinicians, researchers, and other field practitioners are encountering increasing pressure generated by the growing expectations from both the public and the private sector [14]. e-Health institutions have been investing in preventive medicine programs, such as provided by home care and health park, to provide individuals with better life quality and, consequently, reduce hospital check-ins. For instance, patients requiring frequent monitoring, increase the number of check-in at hospitals and clinics, where such patients could benefit from a e-Health environment. Specifically, the health park concept designs a public space to promote preventive medicine initiatives [15]. Thus, patients in a health park and home care environments demand biometry monitoring outside hospital facilities, where wearable IoMT devices and wireless network plays an important role to provide a solution.

In this context, a wide range of e-Health applications relies on wearable sensors, such as smartwatches, fitness tracker, smart glasses, and others to allow non-invasive diagnosis of vital and non-vital functions of the human body [16]. Wearable IoMT devices can sense, collect, and upload biometry data continuously to cloud servers. The cloud runs most of the data processing and analysis. In this context, e-Health applications running on cloud servers require immediate access to biometry information for diagnostic purposes [3]. Examples of data are body temperature, pulse rate, respiration rate (rate of breathing), and blood pressure. This provides opportunities to improve the efficiency of e-Health systems.

The importance of proposing wireless technologies in e-Health facilities is far beyond decreased cost and enhanced mobility. For example, current massive communication over wires in e-Health environments often results in the so-called malignant spaghetti, which is a serious potential hazard for patient safety [13]. In this scenario, LoRaWAN [17] emerge to enable the communication with a group of sensors/devices to provide real-time health monitoring; LoRaWAN has been developed to connect devices that require long-range, low bandwidth, low power, and low-cost communication characteristics, such as, expected for some wearable applications [17].

B. LoRaWAN Technology Outlook

LoRaWAN technology is considered the most adopted LPWAN technology. In particular, Long Range (LoRa) is a proprietary spread spectrum for low power consumption based on Chirp Spread Spectrum (CSS) modulation by Semtech [18]. In this sense, LoRa keeps the low power characteristics of a Frequency Shifting Keying (FSK), while significantly increases the communication range. On top of the LoRa physical layer, LoRa Alliance[1], *i.e.*, a non-profit association, defined the higher layers and network architecture of LoRaWAN. LoRa Alliance counts with 500+ associated members and 100+ LoRaWAN deployments all around the world. The standardization effort focuses on massively deploy a low-cost ecosystem with long-lasting battery lifecycle, bi-directional communication, adaptive data rates, and security schemes.

Usually, four elements in a star topology composes LoRaWAN, namely: (*i*) end-devices, *e.g.*, wearable IoMT device, (*ii*) gateway, (*iii*) network server, and (*iv*) application server, as shown in Figure 1. Network architecture considers a star-of-star topology, granting a single-hop communication between the end-device and gateway over several channels, eliminating the need to build and maintain a complex multi-hop network. Specifically, end-devices broadcast messages for neighbors gateways, which delivers the message to the application server through an IP network. Communication is bi-directional, although uplink communication from the end-devices to network server is strongly favored.

LoRaWAN defines three classes at upper-layer protocol, namely *A*, *B*, and *C* [18]. *Class A* considers Bi-directional and asynchronous transmission always initiated by the wearable IoMT device at a scheduled uplink transmission window. This class enables downlink communication for a short period after uplink. It has high latency and low energy consumption. *Class B* extends the Class A e by adding scheduled receive windows for downlink messages. In this sense, the network synchronizes the wearable IoMT devices using scheduled beacons. It has medium energy consumption and low latency. Class C extends class A by holding receive windows open unless they are transmitting. It has high energy consumption and lowest latency.

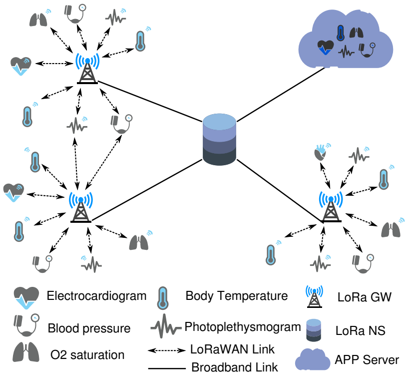

Fig. 1. LoRaWAN for a e-Health Scenario

At the MAC layer, LoRaWAN networks consider the Aloha protocol, which is a random access MAC protocol in which wearable IoMT devices transmit without doing any carrier sensing [18]. The simplicity of Aloha if thought to keep the design of transceiver simple and low cost, enabling a significant increase in node battery life compared to other low power technologies. At the physical layer, LoRaWAN defines a combination of specific radio-related parameters, such as Carrier Frequency (CF), Spreed Factor (SF), Bandwidth (BW), Transmission Power (TP), Duty Cycle (DC), and CR, that can be adjusted, which can increase or decrease the channel utilization on-demand. For instance, LoRaWAN coverage depends on radio-related parameters (mainly SF, Transmission Power (TP), and channel bandwidth used) and environmental conditions where the LoRaWAN gateways and end-devices are deployed [18]. LoRaWAN achieves nearly 2-5 km of coverage range in urban areas and about 45 km in rural areas.

IV. EVALUATION

This section describes the evaluation methodology, including scenario description, simulation parameters, metrics used to evaluate an e-Health scenario over LoRaWAN. In addition, we also discuss some future research direction based on the simulation results and LoRaWAN characteristics in order to improve LoRaWAN performance on a e-Health scenario.

A. Simulation Scenario and methodology

We developed an e-Health application that relies on LoRaWAN to transmit the collected data in the NS-3[2] simulation tool, which implements the LoRaWAN protocol stack for communication between the wearable IoMT devices and the LoRaWAN Gateway. In this sense, LoRaWAN Gateway is prepared to forward LoRaWAN incoming packets all the way down to the Network Server (NS), and expect to receive packets sent by the NS so that delivering in the downlink towards the IoMT devices. NS-3 also implements an error model for LoRaWAN modulation based on baseband simulations of a LoRaWAN transceiver over an additive white Gaussian noise (AWGN) channel [19]. This allows us to reproduce a wearable IoMT device behavior in LoRaWAN. The simulation

---

[1] https://lora-alliance.org/

[2] https://www.nsnam.org/

testbed used in this paper is available as opensource in our Github page[3]. We conducted 33 simulation tests with different and randomly generated seeds fed to the simulator's pseudo-random number generator (MRG32k3a). Each simulation test lasted for 700 seconds and was repeated 33 times, varying the random simulator seeds. Results are shown with a 95% confidence interval.

We consider a LoRaWAN network Class A, which indicates that the wearable IoMT devices always initiate the transmissions in a non-synchronous pattern. In our scenario, every wearable IoMT devices choose a random initial reporting delay, after which the node generates a biometry data traffic following the MGH-MF dataset from the Physionet Databank [20], which contains physiological data from 250 patients monitored at the Massachusetts General Hospital. For this experiment, we selected one hour of sensor data collected from 39 patients who displayed eight biometry measurements. Hence, the biometry data transmissions from patients are driven by a complete dataset featuring ECG (in three channels), arterial, pulmonary, and central venous pressures, O2, and CO2 saturation biometrics. In this work, downlink transmissions, *i.e.*, messages from the LoRaWAN gateways to the wearable IoMT devices, are considered. We do not consider it a significant limitation since we expect most of the traffic in a low power to be uplink.

LoRaWAN imposes the use of at least three mandatory channels at center frequencies 868.1, 868.3, and 868.5 MHz in the European sub-band, which we are using. On sending, the wearable IoMT devices pick one of these three channels randomly. We consider that all the gateways are transmitting with maximum power P_{max} and an antenna gain of G_t. We uniformly deployed wearable IoMT devices (from 1 to 10 thousand) in a $2Km^2$ area. Table I shows the main simulation parameters used in our evaluation.

TABLE I
SIMULATION PARAMETERS

Parameters	Value
Number of Wearable IoMT Devices	[1000-10000]
Simulation Area	2 Km^2
Time Simulation	700 s
Gateway Radius	2000m
Frequency	868 MHz
Bandwidth	125 Khz
Number Channels	3
Propagation Model	Okumura Hata

B. Simulation Results

Figure 2 depicts the packet loss ratio that the e-Health application data transmissions are subjected to coming from the use of a different number of LoRaWAN-enabled IoMT devices. The result analysis reveals that the packet lost rate exponentially grows with the increasing network density. The reason for this packet lost behavior comes from the collisions probability at the LoRaWAN MAC-layer, whereby simultaneous transmissions give rise to higher interference. For instance, the interference of simultaneous packet transmissions with the same SF on the same CF might be unable to be decoded at the gateway. However, intra-network interference can be a severe issue for devices using the same SF value, although LoRaWAN assumes that packets sent in different SF are orthogonal. The results provide evidence that the packet loss experience in LoRaWAN with more than 3 thousand of devices is higher than 20%, which can denote intolerable performance condition for the e-Health application. From 8 thousand devices, the network allows a loss rate of more than 50% of packets, resulting in poor scalability under these severe conditions. It is essential to mention that future e-Health applications and LoRaWAN will be composed of several thousand devices per square meter, leading to Dense IoMT [21].

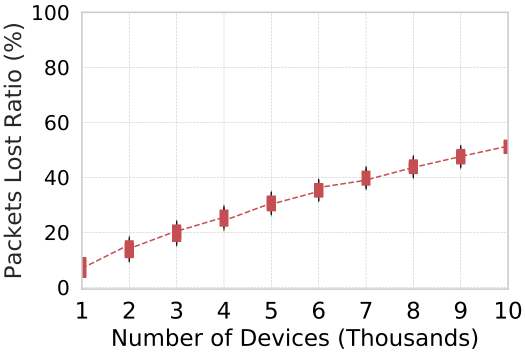

Fig. 2. Packet Loss Ratio for Different Number of Wearable IoMT Devices

Figure 3 shows the number of packets lost due to interference of no channel availability experienced by e-Health application transmitted by LoRaWAN with a different number of IoMT devices. By analyzing the results, we can observe that intra-network interference is the main cause of packet losses since several LoRaWAN were deployed in the same physical space, which leads to inter-network interference. Another type of classical error comes up from the lack of available channels. On the basis that SFs are orthogonal, the existence of different SFs on the same channel is not a problem. The allocation of different devices set with the same SF on the same channel would be a potential strategy to mitigate the issue of lacking available channels. However, Adaptive Data Rate (ADR) is the standard LoRaWAN mechanism to automatically set device SFs, which is not capable of being aware of devices collision in the same channel, increasing the packet loss caused by lack of available channel. Other existing parameters to address interference avoidance, such as the Coding Rate (CR). Specifically, CR stands to as the amount of Forward Error Correction (FEC) that is applied to the message, with the goal to protect against burst interference. Higher CR rate influences the message to become longer, increasing the Time on Air (ToA).

Figure 4 depicts the distance achieved by each SF, as well as the delay that packet transmission with different SF values provide, enabling us to analyze the correlation between distance, delay, and SF. By analyzing the results, we can observe that the higher the SF, the higher both the distance and delay, for the reason that the ToA of each SF is different due to its modulation.

---

[3] https://gitlab.com/gercomlacis/cea/lorawan/lorawan-ns3

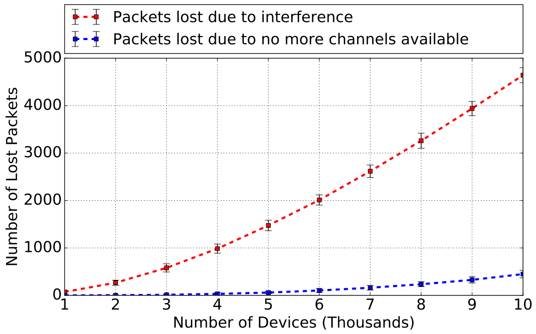

Fig. 3. Types of Packet Loss for Different Number of Wearable IoMT Devices

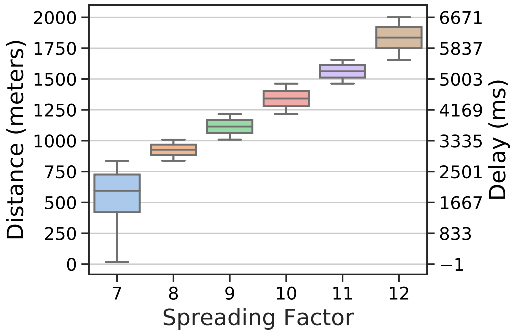

Fig. 4. Delay and Distance for Different SF values

V. KEY RESEARCH CHALLENGES

On the basis of the simulation outcomes, we can conclude that the densification of wearable IoMT devices on a LoRaWAN-enabled system creates a hotspot problem by network overload, resulting in signal interference that affects the application performance due to packet loss caused by collisions [9]. For instance, a LoRaWAN gateway will be unable to correctly decode simultaneous biometrics that wearable IoMT devices send using the same SF on the same channel, *i.e.*, CF. In this context, LoRaWAN provides the flexibility for resource allocation mechanism to configure radio-related parameters adaptively, taking current network conditions and application requirements to reduce packet loss caused by interference.

The resource allocation could adjust on-the-fly a combination of specific radio-related parameters, CF, SF, BW, TP, DC, and CR, providing the trade-off between transmission rate, range, delay, energy, and interference. For instance, each packet can be transmitted in a specific BW, which indicates the frequency range that the communication will occur. For instance, BW can also be set to increase the transmission rate, although the more the BW increases, the smaller the range of a LoRaWAN gateway will be. CF determines the transmission frequency shift, *e.g.*, and it ranges from 137 MHz to 1020 MHz in 61 Hz steps. CR indicates the relationship between the number of bits in the payload and the error correction code values, where a smaller value leads to higher protection against errors with longer packets. SF can be defined as the ratio between the symbol and the chirp rate, where the higher SF values increase the sensitivity and radio range at the cost of an increase in ToA and energy consumption to transmit a packet. For instance, the ToA increases from 659 ms to 1,318 ms for a packet with the payload of 20 bytes transmitted with SF 12 instead of 11m, respectively.

Packet transmission with higher SF values takes much longer to transmit packets at lower rates. This increases the collisions by keeping the channel busy during a more extended time [22]. In addition, SF11 consumes 10-fold more energy for transmission than when using SF7 [23]. Finally, the lowest SF value (*i.e.*, SF equals to 7) supports significantly more devices with lower interference compared to other SFs, due to the relation between the transmission rate and SF [22]. Although SFs are considered to be orthogonal among themselves, *i.e.*, enabling to be easily separated in the receptor to avoid collisions, recent studies have shown that this is not the case by experimentally evaluating the effects of inter-SF interference [24]. An efficient resource allocation holds several possibilities for on-the-fly adjusting the configuration of radio related parameters with the goal to maximize channel utilization while minimizing collisions and interference. Therefore, it is crucial to design a resource allocation to adjust radio-related parameters based on the above findings, maximizing channel utilization, and network performance while minimizing interference, collisions, and energy.

In addition, LoRaWAN considers a set of gateways to cover several devices, where we could add more gateway instances seeking to improve the coverage, and consequently, the LoRaWAN performance. However, increasing the number of gateways will also increase the CAPEX and OPEX, by requiring to deploy a minimal infrastructure for a LoRaWAN gateway, for instance, the cost of a LoRa gateway, cost of leasing, maintain. In this sense, network planning and optimization is an important issue that impacts the QoS, CAPEX, and OPEX [25]. The communication channel between wearable IoMT devices and respective LoRaWAN gateway can be significantly improved, as a result of such efficient LoRaWAN gateway placement, while reduces the CAPEX and OPEX. Furthermore, it is possible to optimize resource allocation together with more appropriate gateway placement, reducing costs while keeping a minimum QoS that fulfills the e-Health application requirements. For instance, an optimum resource allocation setting can cover a more significant area, whereas less gateway needs to be used. One key characteristic of IoMT resides in its dynamic networking characteristics, which means that devices are continually getting in and out of the network, and also might send data with different rate patterns based on application requirements or events. Moreover, it is always important to consider possible physical gateway failures. Hence, it is essential to deploy LoRaWAN gateway to mitigate problems related to dynamic network and gateway failures, combined with resource allocation to provide high reliability and resiliency with low costs for LoRaWAN operations.

Finally, LoRaWAN suffers packet losses at the MAC layer caused by collisions incidence of concurrent transmissions, since ALOHA is oversimplified so that not accounting for channel fading, power control, and aggregate interference, which cannot capture effect due to near-far problem in a cell [26]. Therefore, the MAC layer could be able to prioritize the traffic originated by wearable IoMT devices following either the application requirements or the density of devices for a given application in the attempt to improving the application performance while minimizing the incidence of collisions. In addition, it is also possible to explore synchronization and scheduling functions at the MAC layer, also based on either the application requirements or the device's density for a particular application. Contention Access Period (CAP) needs improvement for non-real-time applications. Specifically, the spreading factor selection strategy needs to consider the signal quality status. Additionally, the network would require dynamic reconfiguration to deal with real case implementations.

VI. CONCLUSION

In this paper, we have discussed the potentials in the utilization of LoRaWAN technology in the scope of the e-Health environment. For instance, the monitored patients in a e-Health scenario demands biometry monitoring by wearable IoMT devices, which collect vital and non-vital functions from the human body in a non-invasive way. These biometric data must be transmitted for e-Health applications running on cloud servers via long-range wireless technology with low energy consumption, such as provided by LoRaWAN. Simulation results provide evidence that, on the one hand, LoRaWAN can be significantly useful to e-Health application use cases, by affording communication up to ten thousands of users. But on the other hand, the scalability capacities of LoRaWAN are limited, being caused by the rising interference of high-dense LoRaWAN-enabled IoMT scenarios. In light of the simulation results, we also introduced a sort of discussion and future directions considering LoRaWAN improvements with the goal of enable e-Health applications.

ACKNOWLEDGMENT

This work is partially supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior — Brasil (CAPES) — Finance Code 001, by the National Council for Scientific and Technological Development (CNPq), and also by PAPQ-PROPESP-UFPA

REFERENCES

[1] I. Yaqoob, I. A. T. Hashem, Y. Mehmood, A. Gani, S. Mokhtar, and S. Guizani, "Enabling communication technologies for smart cities," *IEEE Communications Magazine*, vol. 55, no. 1, pp. 112–120, 2017.

[2] H. Ahmadi, G. Arji, L. Shahmoradi, R. Safdari, M. Nilashi, and M. Alizadeh, "The application of internet of things in healthcare: a systematic literature review and classification," *Universal Access in the Information Society*, pp. 1–33, 2018.

[3] P. Resque, S. Pinheiro, D. Rosário, E. Cerqueira, A. Vergutz, M. Nogueira, and A. Santos, "Assessing data traffic classification to priority access for wireless healthcare application," in *Latin-American Conference on Communications (LATINCOM)*. IEEE, 2019, pp. 1–6.

[4] P. Resque, A. Barros, D. Rosário, and E. Cerqueira, "An investigation of different machine learning approaches for epileptic seizure detection," in *2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC)*. IEEE, 2019, pp. 301–306.

[5] M. M. Baig, H. GholamHosseini, A. A. Moqeem, F. Mirza, and M. Lindén, "A systematic review of wearable patient monitoring systems–current challenges and opportunities for clinical adoption," *Journal of medical systems*, vol. 41, no. 7, p. 115, 2017.

[6] M. A. Santos, R. Munoz, R. Olivares, P. P. Rebouças Filho, J. Del Ser, and V. H. C. de Albuquerque, "Online heart monitoring systems on the internet of health things environments: A survey, a reference model and an outlook," *Information Fusion*, vol. 53, pp. 222–239, 2020.

[7] P. A. Pawar and S. P. Mohammad, "Review of quality of service in the mobile patient monitoring systems," in *2017 IEEE Region 10 Symposium (TENSYMP)*. IEEE, 2017, pp. 1–6.

[8] Q. M. Qadir, T. A. Rashid, N. K. Al-Salihi, B. Ismael, A. A. Kist, and Z. Zhang, "Low Power Wide Area Networks: A Survey of Enabling Technologies, Applications and Interoperability Needs," *IEEE Access*, vol. 6, pp. 77 454–77 473, 2018.

[9] R. Sanchez-Iborra, J. Sanchez-Gomez, J. Ballesta-Viñas, M.-D. Cano, and A. Skarmeta, "Performance evaluation of lora considering scenario conditions," *Sensors*, vol. 18, no. 3, 2018.

[10] G. Pasolini, C. Buratti, L. Feltrin, F. Zabini, C. De Castro, R. Verdone, and O. Andrisano, "Smart city pilot projects using lora and ieee802. 15.4 technologies," *Sensors*, vol. 18, no. 4, p. 1118, 2018.

[11] M. T. Buyukakkaslar, M. A. Erturk, M. A. Aydin, and L. Vollero, "Lorawan as an e-health communication technology," in *2017 IEEE 41st Annual Computer Software and Applications Conference (COMPSAC)*, vol. 2, July 2017, pp. 310–313.

[12] M. L. S. M. P. A. Catherwood, D. Steele and J. Mclaughlin, "A community-based iot personalized wireless healthcare solution trial," *IEEE Journal of Translational Engineering in Health and Medicine*, vol. 6, May 2018.

[13] K.-J. Park, H.-H. Lee, S. Choi, and K. Kang, "Design of a medical-grade qos metric for wireless environments," *Transactions on Emerging Telecommunications Technologies*, vol. 27, no. 8, pp. 1022–1029, 2016.

[14] E. Omanović-Mikličanin, M. Maksimović, and V. Vujović, "The Future of Healthcare: Nanomedicine and Internet of Nano Things," *Folia Medica Facultatis Medicinae Universitatis Saraeviensis*, vol. 50, 2015.

[15] R. Arena, S. Bond, R. O'Neill, D. R. Laddu, A. P. Hills, C. J. Lavie, and A. McNeil, "Public park spaces as a platform to promote healthy living: introducing a healthpark concept," *Progress in cardiovascular diseases*, vol. 60, no. 1, pp. 152–158, 2017.

[16] K. Tehrani and A. Michael, "Introduction to Wearable Technology," 2017, [online] http://www.wearabledevices.com/what-is-a-wearable-device (accessed date: Oct. 2017).

[17] R. Fernandez-Garcia and I. Gil, "An Alternative Wearable Tracking System Based on a Low-Power Wide-Area Network," *Sensors*, vol. 17, no. 3, 2017.

[18] J. Haxhibeqiri, E. De Poorter, I. Moerman, and J. Hoebeke, "A survey of lorawan for iot: From technology to application," *Sensors*, vol. 18, no. 11, p. 3995, 2018.

[19] F. Van den Abeele, J. Haxhibeqiri, I. Moerman, and J. Hoebeke, "Scalability analysis of large-scale lorawan networks in ns-3," *IEEE Internet of Things Journal*, vol. 4, no. 6, 2017.

[20] J. P. Welch, P. J. Ford, R. S. Teplick, and R. M. Rubsamen, "The massachusetts general hospital-marquette foundation hemodynamic and electrocardiographic database – comprehensive collection of critical care waveforms," Available at https://physionet.org/physiobank/database/mghdb/ (2018/12/19), 1991.

[21] N.-N. Dao, D.-N. Vu, W. Na, J. Kim, and S. Cho, "Sgco: Stabilized green crosshaul orchestration for dense iot offloading services," *Journal on Selected Areas in Comm.*, vol. 36, no. 11, pp. 2538–2548, 2018.

[22] A. M. Yousuf, E. M. Rochester, B. Ousat, and M. Ghaderi, "Throughput, coverage and scalability of lora lpwan for internet of things," in *IEEE/ACM 26th International Symposium on Quality of Service (IWQoS)*. IEEE, 2018, pp. 1–10.

[23] A. Duda and M. Heusse, "Spatial issues in modeling lorawan capacity," in *22nd International ACM Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, 2019, pp. 191–198.

[24] L. Amichi, M. Kaneko, E. H. Fukuda, N. E. Rachkidy, and A. Guitton, "Joint allocation strategies of power and spreading factors with imperfect orthogonality in lora networks," *arXiv preprint arXiv:1904.11303*, 2019.

[25] H. Tian, M. Weitnauer, and G. Nyengele, "Optimized gateway placement for interference cancellation in transmit-only lpwa networks," *Sensors*, vol. 18, no. 11, p. 3884, 2018.

[26] J. Lyu, D. Yu, and L. Fu, "Achieving Max-Min Throughput in LoRa Networks," *arXiv preprint arXiv:1904.12300*, 2019.